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Ireneusz LIPIARSKI, Stanisław ĆMIEL

The geological conditions of the occurrence of Carboniferous coal in the northwestern part of Sörkap Land in West Spitsbergen

ABSRACT: The aim of geological investigations the results of which are given in this paper was identify the presence of Carboniferous coal in the area south of Hornsund (Figs. 1 and 2).

The field investigations were carried out in the summer of 1979 within the scientific expedition organized by the Institute of Geophysics of the Polish Academy of Sciences (problem MR-II-16/B). The investigations covered the northwestern part of Sörkappland, south of Hornsund and west of the Wurmbrandegga and Wiederfjellet (Fig. 2).

Key words: Arctic, Carboniferous coal, West Spitsbergen

1. Introduction

The area under investigation varies morphologically. Along the shoreline there is a flat, low sea terrace, 2–3 km wide and cut by small streams. In the western part, where there are some shallow water reservoirs, most of the area is covered by tundra vegetation.

The hill range Struvefjella, in the central part of the investigatin area, comprises there hills: the Hohenlohefjellet (+614 m), the Sergeijevfjellet (+412 m, +437 m) and the Lidfjellet (+513 m), whose steep slopes descend to the east in Lisbetdalen, with Svartvatnet, the largest water reservoir in the area. The terrain rises east of Lisbetdalen and the hills: the Savitsjtoppen (+464 m) and the highest hill in the area, Kovalevskifjellet (+640 m) occur here.

Carboniferous rocks occur in the area of the sea terrace (Hornsundneset Formation). They are covered by a moraine, coarse-clastic rocks of the sea terrace, and sandstone detritus of the Hornsundneset Formation. Vegetation covers part of the area. The hills are, partly or completely, built of Carboniferous rocks (Hornsundneset and Sergeijevfjellet Formations, Siedlecki 1960). The upper part of some hills are covered by Triassic rocks (Varde-

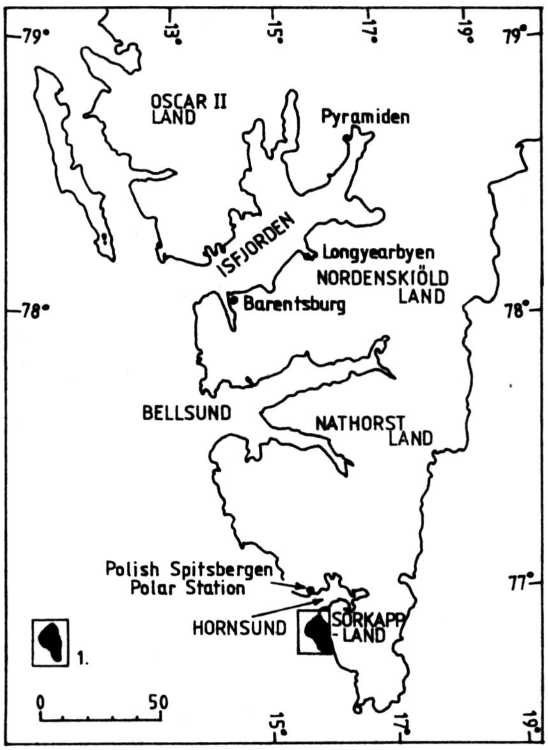

Fig. 1. The location of the investigation 1—the area shown in Fig. 2; Carboniferous rocks are marked in black

bukta Formation, Birkenmajer 1977; Fig. 2, Table I). The slopes of the hills are usually covered by a thick layer of rocks detritus.

The investigations focussed on Carboniferous rocks. Two lithostratigraphic profiles of the Sergeijesfjellet Formation were made both at the Hohenlohefjellet and at the Sergeijevfjellet; and one profile of the Sergeijevfjellet at the Lidfjellet. The profiles were made at spots with good exposure or where the layer of detritus is relatively thin and readily removable.

The present paper describes rocks of the Hornsundneset Formation and the profile of the Sergeijevfjellet Formation made on the northwestern slope of a hill 412 m high (Sergeijevfjellet). In the authors' opinion, this profile is typical of the Sergeijevfjellet Formation (Fig. 3, Table I).

2. The geological situation of the investigation area.

The Carboniferous deposits unconformally on the metamorphic rocks of the Hecla Hoek Succesion (Precambrian, Ordovician, Birkenmajer 1977). Locally (Sigfredbogen), the Carboniferous deposits are superposed on a thin

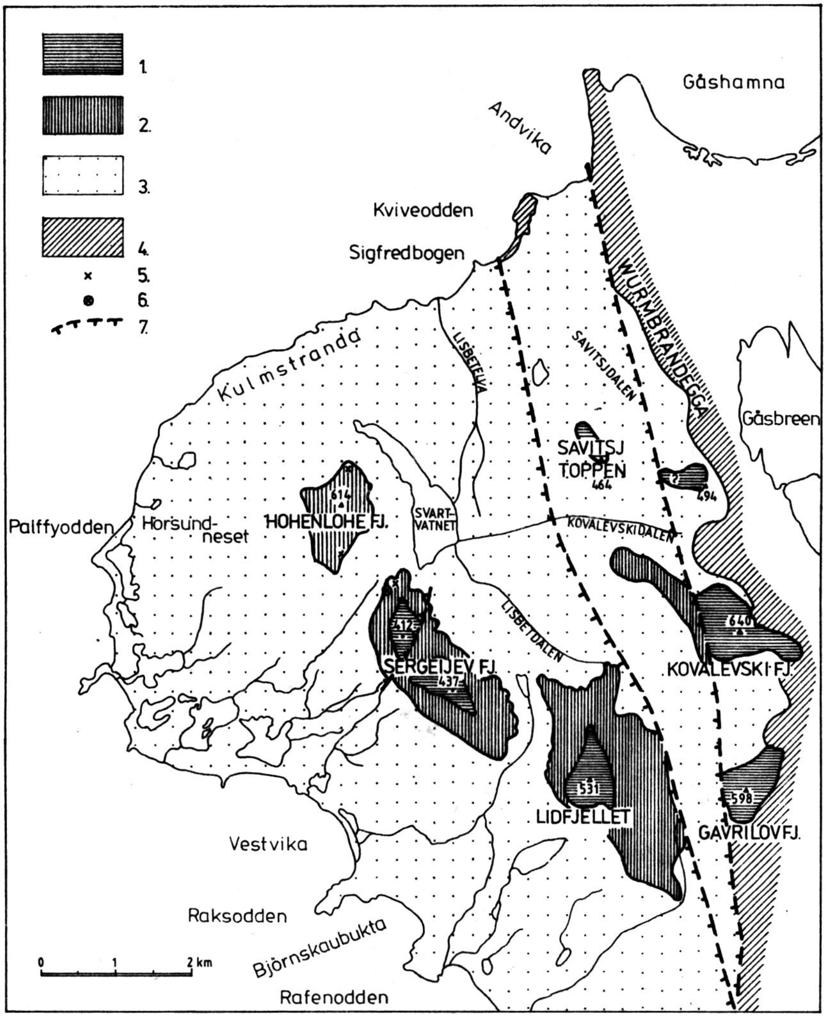

Fig. 2. A geological map of the investigation area (according to K. Birkenmajer 1964, modified) 1—Triassic, 2—Sergeijevjellet Formation, 3—Hornsundneset Formation, 4—Hecla Hoek Succession (without differentiation), 5–6 the location of the lithostratigraphic profiles of the Sergeijevfjellet Formation, 5—the profile of the Sergeijevfjellet Formation described in this paper, 7—Tertiary faults.

conglomerate layer which, Siedlecki (1960) believes, is Devonian. Also unconformally, Triassic deposits (Vardebukta Formation, Birkenmajer 1977), moraines and rocks of Holocene terraces lie on Carboniferous ones. The latter are exposed over a large part of the area.

The tectonics of the Carboniferous rocks is relatively simple. The rocks of the Hornsundneset and Sergeijevfjellet Formations form a syncline whose longitudinal axis, from the Hohenlohefjellet on, descends southeast, i.e. towards the Lidfjellet. In the rocks of the two Formations a layer inclination

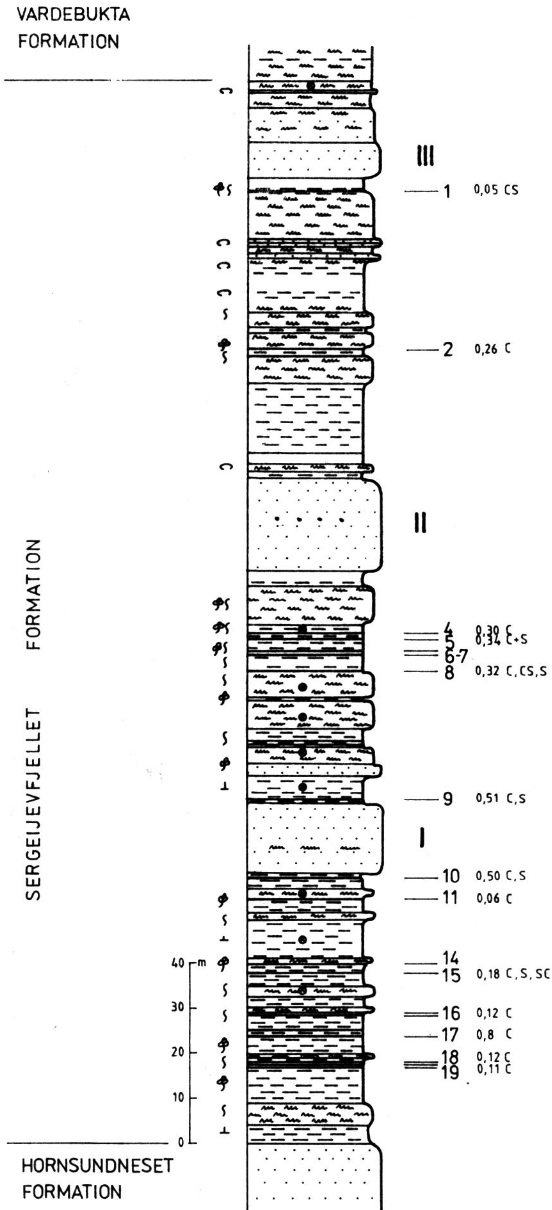

Fig. 3. The lithostratigraphic profile of the Sergeijevfjellet Formation 1—sandstone, 2—mudstone, 3—siltstone, 4, coal carbonaceous shale (the number of a bed and its thickness are given by profile), 5—limestone, sanded limestone, 6—siderite concretions, 7—determinable flora, 8—rootlets, 9—detritus plants, 10—fauna; c—coal, cs—carbonaceous shale, s—siltstone, sc—sapropel coalis; I—III the numbers of "quartcite" sandstone complexes.

Table I.

The stratigraphy of rocks in the northwestern part of Sörkappland

Chronostratigraphy	Lithostratigraphy	Location of profile	Generalized lithological description
Triassic	Vardebukt Formation (K. Birkenmajer 1977)	Sergeijevfjellet	Grey siltstones and mudstones fine-grained sandstones
Carboniferous (Lower Namurian, acc. to S. Siedlecki and E. Turmau 1964)	Sergeijevfjellet Formation (230 m thick, acc. to the authors)		Fine-grained, compact („quartzite") sandstone, mudstone and grey siltstone with carbonate binder and fauna, limestone with fauna, humus and sapropel coal, carbonaceous slate and carbonaceous siltstone, about 20 layers of coal rocks
	Hornsundneset Formation (700—750 m thick acc. to S. Siedlecki)	Hornsundneset Hohenlohefjellet	Different-grained sandstone locally puddingstone-like, mudstone. Single layers of carbonaceous slate and carbonaceous siltstone
Devonian? (acc. to S. Siedlecki 1960)		Cliff Sigfredbogen and Krivebodden	Lithic and/or quartz puddingstone
Precambrian (acc. to K. Birkenmajer 1977)			Metamorphic rocks

of 0° to 20° to the south, southwest and west noted. Locally, near tectonic dislocations, the inclination of layers increases, while the orientation of the declines changes to the east or north (Lidfjellet).

Two parallel, meridional faults were found in the eastern part of the area (Major, Winsnes 1955). A number of small faults were noted in the area of the Struvefjella hills. Some faults can also be seen in the flat top of the Hohenlohefjellet. On a hill 412 m over the sea level Siedlecki (1960) found a fault with a small throw, which cuts across the rocks of the Sergeijevfjellet Formation and Triassic rocks. A fault with a greater throw cuts down the Triassic rocks on the southeastern side of the hill +412 (Major, Winsnes 1955). The inclination angle of the planes of the faults usually exceeds 70°. The throw of the faults observed in the area varies between several and dozen-odd m. The fault cut across Carboniferous and Triassic rocks. These dislocations formed or were rejuvenated in the Tertiary period. Apart from the dislocations, some small undulations occur at the Hohenlohefjellet and Sergeijevfjellet.

3. A review of the literature on the geology of the Carboniferous deposits in Sörkapp Land

For a number of years the Carboniferous deposits in Spitsbergen were called "Culm". This term was introducend by Nathorst (1910). Later Cutbill and Challinor (1965) prosed a formal name for the Culm deposits: the Billefjorden Group.

Mentions about the Culm deposits Sörkappland date from the early 20th century (Nathorst 1919, p. 329, vide Hoel 1929). Short information about it was also given by Hoel (1929, p. 34), who found that the Hohenlohefjellet is built of Culm sandstones; and coal pieces were found in the tali on the slopes of this hill. Orvin (1940, p. 22) compared the profile of the Culm in Sorkappland with that of Isfjorden. He also mentioned coal beds accompanying dark shales with fossils and thick sandsone ledges. He estimated the total tickness of Culm rocks at about 1000 m. A review geological map of the area under consideration, which shows the Carboniferous deposits without stratigraphic differentiation, is given both in the 1955 paper of Major and Winsnes and in that of Flood, Nagy, and Winsnes (1971).

Detailed investigations of the Culm deposits were carried out by Siedlecki (1960) in the area west of the Wurmbrandegga. He found that the Culm consists of 2 parts. The lower part which he termed the Hornsundneset Beds, 700–750 m thick, is built mainly of sandstone. The upper part, i.e. the Sergeijfjellet Beds, about 180 m thick, is, in turn, built of siltstone interlayered with sandstone and a coal seam. This division of the Culm proposed by Siedlecki was accounted for in a geological map elaborated by Birkenmajer (1964). The Hornsundneset and Sergeijevfjellet Beds later were given the rank of a formal lithostratigraphic formation (Cutbill and Challinor 1965). The palynological investigations of Turnau indicated the Lower Namurian age of the assotiation of the miospor from the Hornsundneset and Sergeijevfjellet (Siedlecki and Turnau 1964).

4. A Lithostratigraphic characteristic of Carboniferous deposits in the northwestern part of Sorkapp Land

4.1. The Hornsundneset Formation

The rocks of the Hornsundneset Formation are exposed in the cliff seashore and in the area of the sea terrace, from Andvika in the western part to as for as Raksodden in the southern part and in the lower part of most hills (Fig. 2). In the Kulmstranda cliff there are exposed rocks of the lower part of the profile of the Formation (Siedlecki 1960). The upper part of this Formation is exposed at Hornsundneset and in the northeastern slope of the Hohenlohefjellet.

The Formation consists mainly of thick—or medium—layer, creamcoloured "quartizite" sandstone; locally, of the conglomerate type in the lover part of the Formation. Fine-clastic rocks are rare. Thin layers of these rocks are usually covered by of sandstone blocks and, therefore, difficult to distinguish in the field. In three exposures amidst the fragments of the grey silstone with rootlets and small coal pieces was found. The way in which the coal and siltstone are present suggests that they occur here in situ (compact rock lies sevral score cm below, in the zone of permafrost). Two exposures occur west of the hill 412 m over the sea level (Sergeijevfjellet), while there is one exposure among the sandstone blocks, east of Savitsjdalen. It can be presumed, on the basis of the detitus material, that layers of coal and carbonaceous shale reach a small thickness, from several to dozen-odd cm. It is possible that in the Hornsundneset Formation there are more interbedded coal deposits (coal, carbonaceous shale and silstone.). They are, however, covered by sandstone detritus and it is therefore difficult to discern them on the surface.

4.2. The Sergeijevfjellet Formation

The fullest profile of deposits of the Carboniferous Sergeijevfjellet Formation is exposed in the nortwestern slope of the hill 412 m over the sea level (Fig. 2). This hill is the northern, lower part of the Sergeijevfjellet. In this exposure the stratigraphic thickness of this Formation is about 230 m, from the roof of the sandstones of the Hornsundneset Formation to the floor of Triassic rocks (Fig. 3, Table I). Siltstone and mudstone, grey olivegrey in colour, with rootlets and stigmaria, plants detritus and large plants fossils, dominate in the profile. They are characterized by a thinlayered, rarely massive, structure. Fine-grained "quartizite" sandstone, cream-coloured on the altered surface, is the most characteristic. It builds complexes from several to more than 20 m thick, which are distinct in the field in the form of "rocks", play the role of lithostratigraphic horizons with leading significance. In the upper part of the Formation different-grained sandstone was found with fauna, light brown on the eroded surface. In the profile there are three horizons of "quartizite" sandstone, two of which with greater thickness, I and II, divide the Sergeijevfjellet into 3 parts, while level III, thinner than the other two, lies at the top of the Formation (Fig. 3). Several sections with cyclic structure can be distinguished in the sequences between thick sandstone layers.

Apart from sandstone, mudstone, and siltstone, in this Formation there are limestone and sanded limestone, concretions of silty siderite and of limonite, humus carbonaceous shale sapropel shale, carbonaceous siltstone, humus and sapropeic coal. Fig. 3 shows the stratigraphic order of these rocks.

4.21. A lithological characteristic of coal rocks

Humic coal is built vitrain, durain, fusain and clarain. Vitrite occurs in the form of thin layers whose thickness does not exceed 3 mm. Locally its thickness reaches 10 mm. Fusain is practically indiscernible visually; it forms very thin lenses. Durain occurs infrequently in the form of layers whose thickness does not exceed 1–2 cm. Fine-layered clarain is the main component of the coal. At some points in the coal there is dispersed clay; its presence decreases the lustre and increases the compactness and bulk density of the coal.

Humic carbonaceous slate is a rock with bedded structure, built of thin layers of interbedded siltstone and coal. The layers of coal, mostly vitrain, and of siltsone in the area investigated are usually a thickness less of 1 mm to several mm. At spots layers (lenses) of vitrain reach a thickness of 10 mm. Thinly laminated carbonacous shale is most frequent. In the horizontal direction the carbonaceous slate turns into silstone with vitrite layers or into coal.

Carbonaceous silstone is built of silt and varying amount of coal matter, usually in very fine pieces which are not discernible visually. As the content of the coal matter increases, the bulk density of the carbonaceous siltstone decreases, while the colour becomes increasingly black and the lustre more intensive. In the profiles investigated carbonaceous siltstone occurs in the form of a weakly compact rock with scaly structure. In the horizontal direction, at some spots, it turns a continuous manner into silted coal.

Sapropel coals shows greasy lustre, black colour and dark brown and black crack. It is compact, characterized by separation parallel to bedding, and does show separation along stratification. Moreover, it has relatively low bulk density and its properties are similar to those of durain, a lithotype of humic coal, from which it is different in, among other things, the presence of the perpendicular separation to stratification.

Sapropel shale is characterized by brown and black colour, grey and brown crack, bedded structure and very good separation along stratification which results, in this case, from the presence of plants fossils on the layer planes. The perpendicular separation to stratification is less distinct that in sapropelic coal. In the rock there is a large amount of silt matter; in view of this, it has relatively large bulk density.

4.2.2. The lithological structure of coal seams

More than 20 layers of coal, carbonaceous shale and carbonaceous silstone were found in the Sergeijevfjellet Formation at the Sergeijevfjellet (Fig. 3). These coal seams are single—or multi-layer in structure. Single-layer coal seams consist of one coal layer; they are not interbedded with or bass.

Multi-layer coal seam consist of several coal layers interbedded with siltstone mudstone, carbonaceous shale and carbonaceous siltstone. Coal layers and gangue which make up a multi-layer coal seam vary in thickness and order. In seam 15, layered carbonaceous silstone and sapropel slate co-occur with humic coal. In the other shale, coal is interlayered with siltstone. Layers of carbonaceous shale and siltsone are more frequent in the floor than in the roof of a coal seam[1]).

Sapropelic coal is usually present in the from of a thin layer only in bed 15. jointly with humic coal, black carbonaceous silstone, and sapropelic shale.

The structure of coal seams changes in the horizontal direction. To the northwest, i.e. towards the Hohenlohefjellet, the content of silt matter increases in coal. Some coal seams turn into carbonaceous shale or carbonaceous siltstone, which is indicated by a lesser number of coal layers in the profile at the Hohenlohefjellet. Coal seams which occur in the lower part of the Sergeijevfjellet Formation on the hill 421 m over the sea level thin out over 1.5 km to the north, i.e. in the area between the hill 412 m over the sea level and the northen part of the Hohenlohefjellet.

In the roof and the floor coal beds contact with non-carbon, clastic rocks, carbonaceous shale or carbonaceous siltstone.

In the floor of coal, carbonaceous shale and carbonaceous silstone there is siltstone, usually with rootlets. Quite frequently there is a large number of rootlets, often accompanied by Stigmarial. Rootlets also occur in siltsone or mudstone which separate coal layer.

In the roof of the coal there are rocks with detritus plants and large fossils plants along stratification. At some spots in these rocks also rootlets are presented.

4.2.3. The thickness of coal seams

The thickness of single-layer coal seams in the hills Hohenlohefjellet and Sergeijevfjellet varies between 0.02 m to 0.48 m.

Among the multi-layer seams, No 10 is 0.50 m thick, including one siltstone

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[1]) Thy lithology and patrogrphy of coals seams will be described in detail in another paper.

interbedding 1 cm thick; seams No 9, in turn, is 0.51 thick and included a 5 cm layer of carbonaceous siltstone. Some coal seams consist of coal layers with thickness exceeding 0.20 , (seam No 2—0.26 m, seam 4—0.30—0.48 m, seam 9—0.40—0.51 m, and seam No 10—0.28—0.50 m). The thickness of coal layers in other sems is several to dozen-odd cm. The sapropelic coal seam in the Sergeijevfjellet (seam No 15), which is usually 6–8 cm thick, locally grows to about 1 m.

At places, coal is accompanied by carbonaceous shale and carbonaceous siltstone, which locally increases the thickness of a coal seam with complex structure. E.g. in one of exposures, seam No 4/5, which consists of 5 layers, is 0.80 m thick, whereas bed 9, of 5 layers, and bed 15, of 7 layers, reach thickness above 0.60 m.

4.2.4. The form and range of the coal seams of the Sergeijevfjellet in the nortwestern part of Sörkapp Land

The coal seams (carbonaceous shale and carbonaceous siltstone) in the area investigated have the form of flat lenses thinning out over a small area, The No 15 seam of sapropelic coal or sapropelic shale which covers a relatively wide range has locally the form of a small-size pocket.

The range of coal seams does not really extend beyond the two hills, Sergeijevfjellet and Hohenlohefjellet, Very thin layers of carbonaceous siltstone and one coal layer 3 cm thick were found in the upper part of the profile of the Sergeijevfjellet in the southern slope of the Lidfjellet. No coal was observed in the exposures in the western slope of the Lidfjellet. It seems therefore that between the Sergeijevfjellet and the Lidfjellet coal rocks thin out. Towards the Hohenlohefjellet the coal-bearning formation decreases in coal content. No coal seams were found in the area of the Kovalevakifjellet, west of the Struvefjella, in the Sergeijevfjellet Formation.

4.2.5. The coal quality

Six coal samples from beds localized in the lower and central part of the Sergeijevfjellet Formation were investigated technologically and chemically. In view of the large content of mineral matter in the of coal, piece coal samples without interbedded rocks other than coal were used.

The ash content in the coal samples varied from 2 to 30 per cent. Since the analyses were carried out on spot samples, the results are not representative of the whole coal beds. It should be expected that the mean ash content in most coal beds greatly exeeds 30 per cent. The coal contains a relatively low amount of hygroscopic humidity. In the air-dry coal the content of hygroscopic humidity is about 1 per cent on average and does exceed 2 per cent in any sample.

The content of volatile matter varies between 15 and 23 per cent. Three samples a smaller content of volatile matter (15–18 per cent); the other three, however, exhibit a greater amount of it (22–23.3 per cent). The coal contains from 81 to 88 per cent of the carbon content and from 4 to 5 per cent of hydrogen. The coal is not caking and, accordingly, it does not form compact coke.

The reflection coefficient was determined for one of the samples. The mean reflection coefficient, when measured in an oil bath with the $n = 1.515$, at a temperature of 20°C, and in the light with the wavelength $\lambda = 546$ m,μ, is $R^{\circ} = 1.41$ per cent.

The technological investigations carried out on 6 coal samples show a relatively high range of coalification (types 300 and 400 of the international classification of hard coal). The reflection coefficient R° and the content of the element C indicate less carbonated coal.

5. Conclusion

In the northwestern part of Sörkappland the Carboniferous rocks (Billefjorden Group) are represented by two formations: the Hornsundneset Formation and the Sergeijevfjellet Formation. In the Hornsudneset Formation there are single, thin layers of carbonaceous shale, where in the Sergeijevfjellet Formation, 230 m thick, about 20 seams and layers of coal, carbonaceous slate and Carbonaceous siltstone were found. The coal beds are several cm to about 0,50 m thick. They are lens-shaped with limited range. Their horizontal range is limited to the area of the hills Sergeijevfjellet and Hohenlohefjellet.

The coal seams are interbedded with siltstone. In the coal there is also a large amount of dispersed silt matter. The coal shows high range of coalification and does not have the coking properties.

In view of the small range of the coal seams their low thickness and the large ash content in the coal, their industrial (economic) significance in the region is now very small.

The coal seams formed probably over a small area. The presence of rootlets in the silt rock underlying the seams of coal, carbonaceous shale and carbonaceous siltstone indicates that these rocks formed in situ. The frequent siltstone interbeds in the coal and the large amount of dispersed silt matter in the coal suggest that mineral matter and plants ware simultaneously. Below of the level II of "quartizite" sandstone the clastic rocks of the lower and central parts of the Sergeijevfjellet formed only in land conditions, with a continuous supply of plants detritus. The numerous rootlets which occur in silt rocks in many parts of the profile indicate that Lepidophyta continuously settled the area in question. These plants seem to have played the most important role in the formation of coal beds.

The coarse clastic rocks with fauna and the limestone beds with fauna which occur over level II of "quartizite" sandstone formed in a lacustrine or marine environment. The other kinds of rock in this part of the profile formed, at least partly, in a land environment.

6. Резюме

Целью геологических исследовании, результаты которых представлены в статье, была разведка залежей угля формации карбона в районе, расположенном на юг от Горнзунда и на запад от Вурмбрандегга и Видерфьеллет (фиг. 2).

7. Streszczenie

Celem badań geologicznych, których wyniki są przedstawione w niniejszej pracy, było rozpoznanie występowania węgla w formacji karbońskiej w rejonie położonym na południe od Hornsund i na zachód od Wurmbrandegga i Wiederfjellet (fig. 2).

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